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(54) **SERVO WRITING METHOD, MAGNETIC DISK APPARATUS AND HEAD POSITION CONTROL METHOD**

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G11B 5/596 (2006.01)

(52) **U.S. Cl.**
CPC ***G11B 5/59627*** (2013.01); ***G11B 5/59666*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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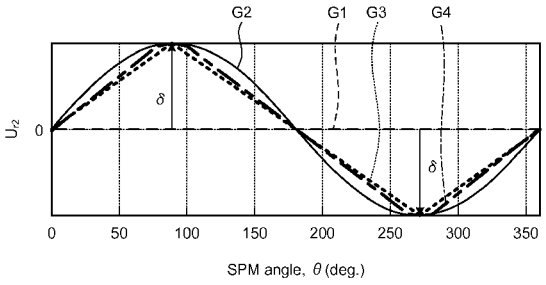
(57) **ABSTRACT**

According to one embodiment, a servo writing method for a magnetic disk apparatus that includes a magnetic disk and a head is provided. The method rotates the magnetic disk, derives a path obtained by adding a second specifying value to a first specifying value, the first specifying value corresponding to a separation distance from a rotation center of the magnetic disk, the second specifying value periodically displacing the separation distance in a radial direction synchronously with a rotation angle of the magnetic disk, the second specifying value being a value in which the separation distances at a start point and an end point of one rotation of the magnetic disk coincide, and, while causing the head to follow the path, writes servo information onto the magnetic disk with the head.

15 Claims, 8 Drawing Sheets



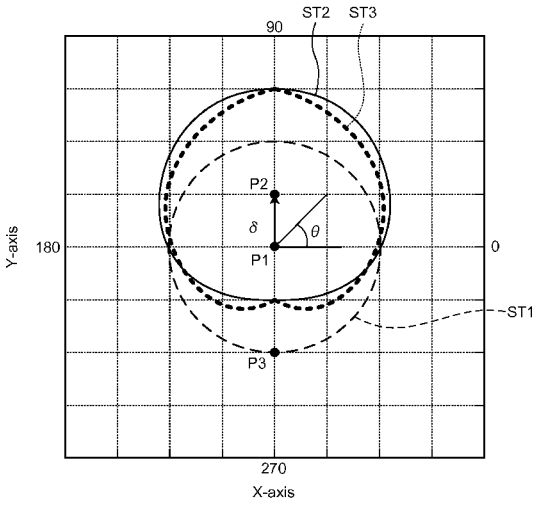


FIG.1

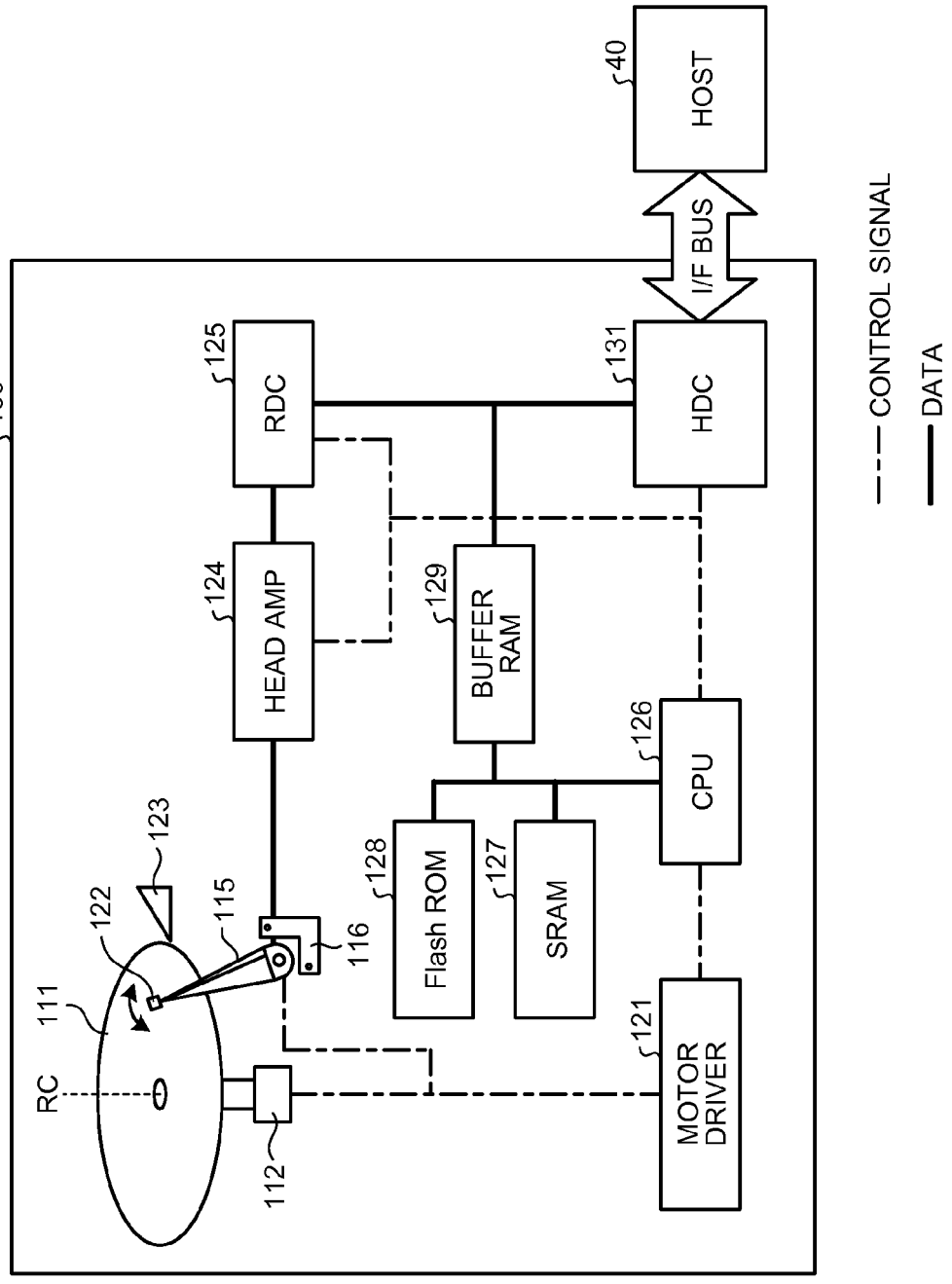

100
40
HOST
I/F BUS
125
RDC
131
HDC
124
HEAD AMP
129
BUFFER RAM
126
CPU
128
Flash ROM
127
SRAM
123
122
115
116
111
RC
112
121
MOTOR DRIVER
CONTROL SIGNAL
DATA

FIG.2

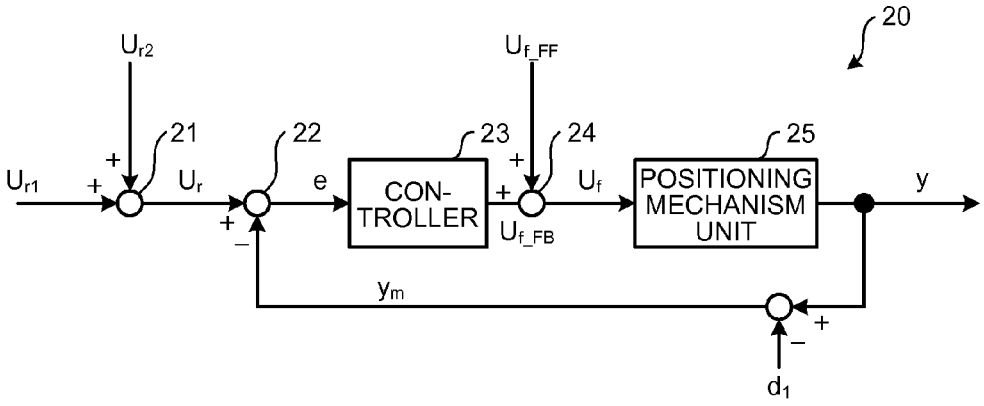

20
U_{r2}
U_{f_FF}
21
22
23
24
25
U_{r1}
+
+
U_r
e
CON-
TROLLER
+
U_f
POSITIONING
MECHANISM
UNIT
y
+
−
U_{f_FB}
y_m
+
−
d_1

FIG.3

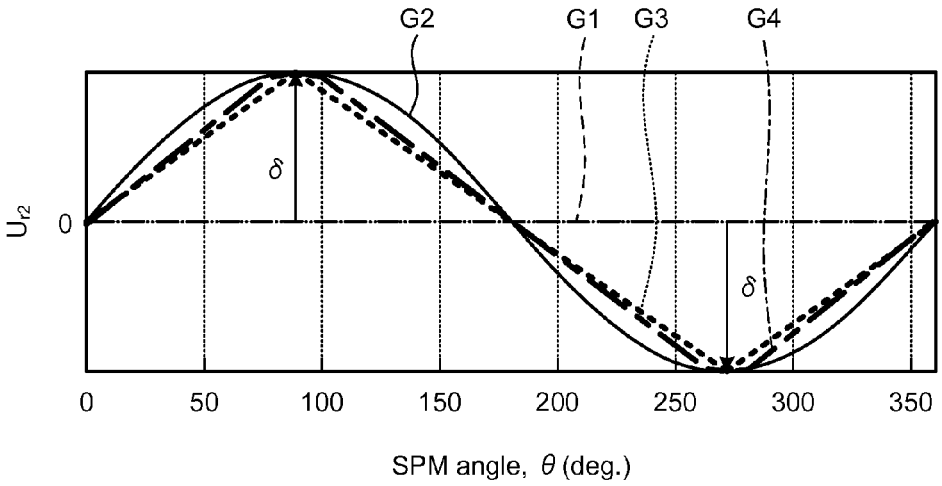

G2
G1
G3
G4
U_{r2}
0
δ
δ
0
50
100
150
200
250
300
350
SPM angle, θ (deg.)

FIG.4

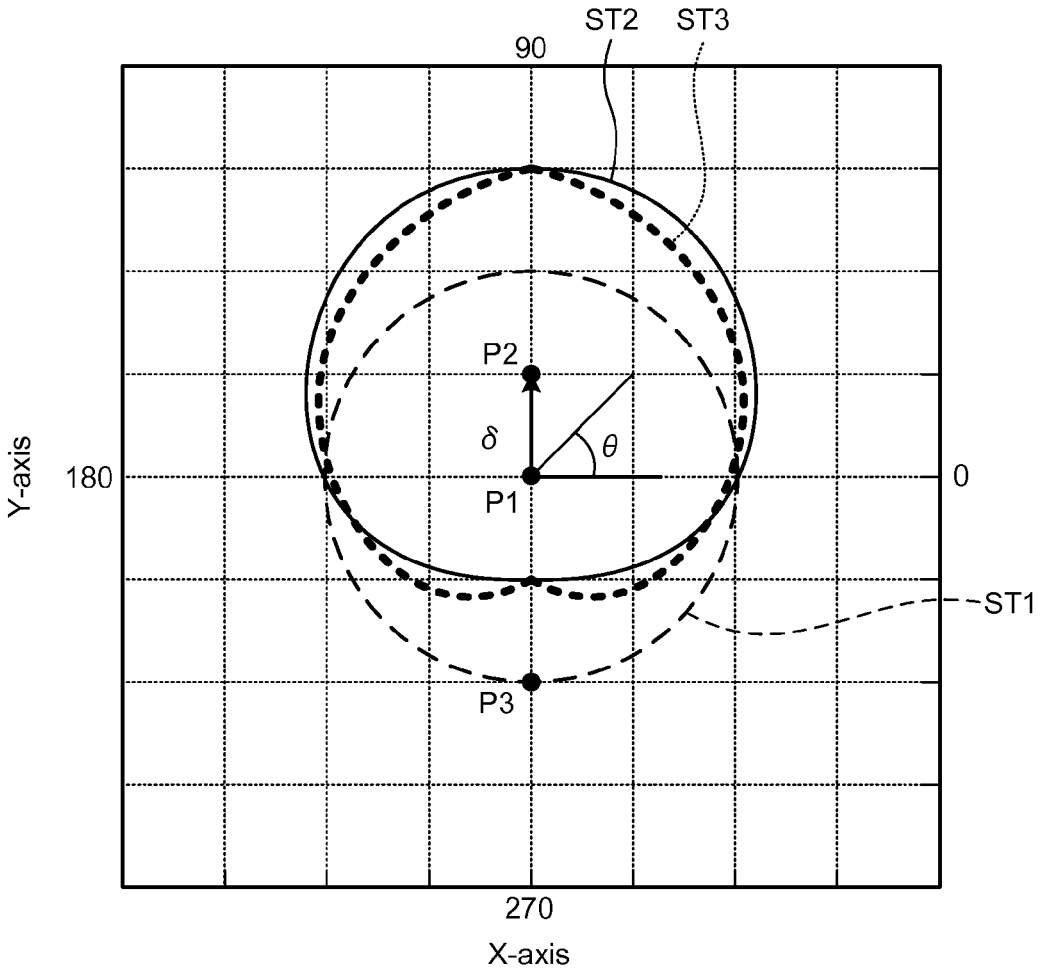


FIG.5

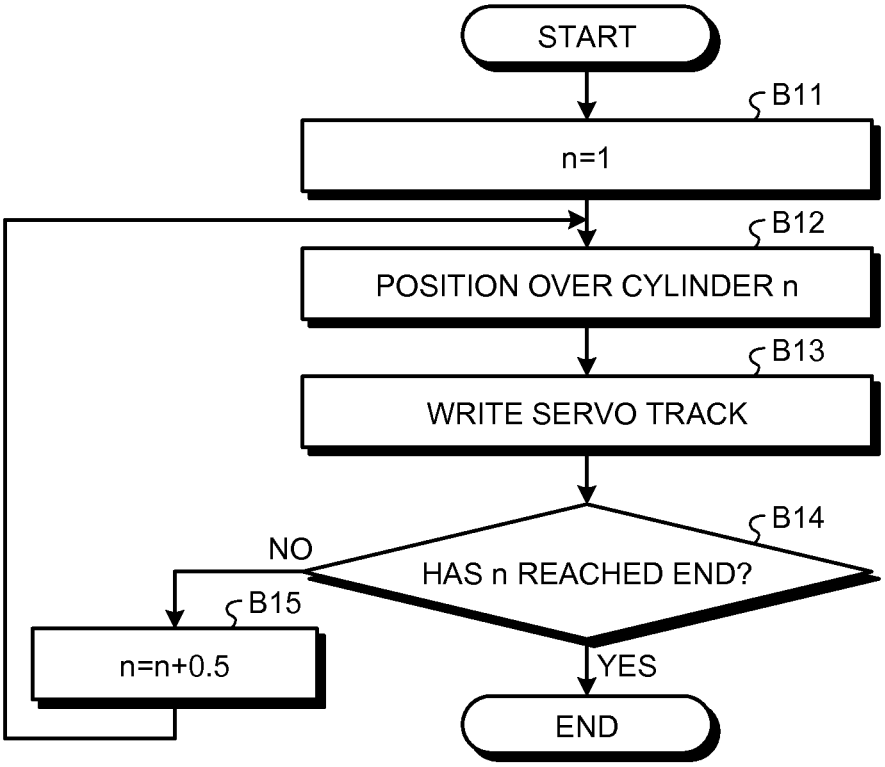

START
B11
n=1
B12
POSITION OVER CYLINDER n
B13
WRITE SERVO TRACK
B14
HAS n REACHED END?
NO
B15
n=n+0.5
YES
END

FIG.6

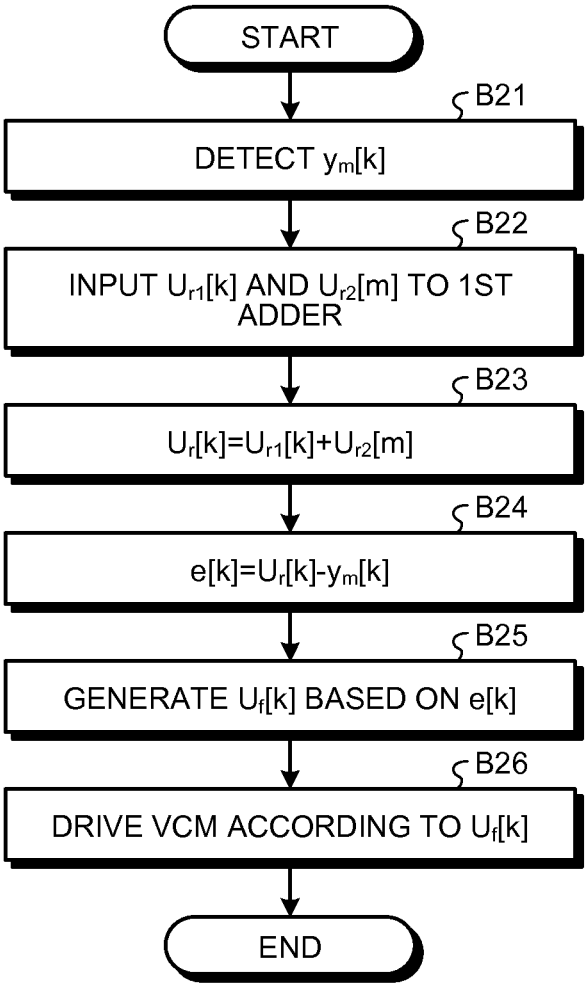

START
B21
DETECT $y_m[k]$
B22
INPUT $U_{r1}[k]$ AND $U_{r2}[m]$ TO 1ST ADDER
B23
$U_r[k]=U_{r1}[k]+U_{r2}[m]$
B24
$e[k]=U_r[k]-y_m[k]$
B25
GENERATE $U_f[k]$ BASED ON e[k]
B26
DRIVE VCM ACCORDING TO $U_f[k]$
END

FIG.7

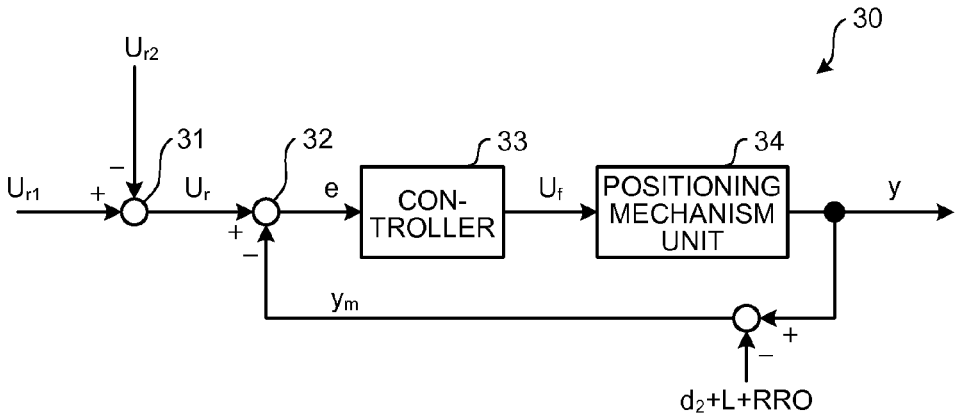

30
U_{r2}
31
32
33
34
U_{r1}
+
−
U_r
e
CON-
TROLLER
U_f
POSITIONING
MECHANISM
UNIT
y
+
−
y_m
+
−
d_2+L+RRO

FIG.8

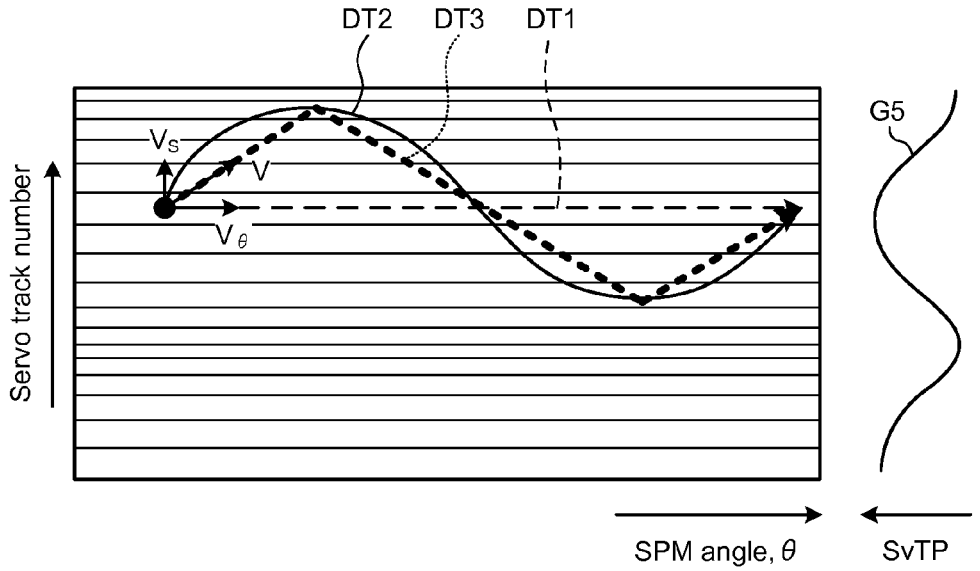

DT2
DT3
DT1
G5
V_S
V
V_θ
Servo track number
SPM angle, θ
SvTP

FIG.9

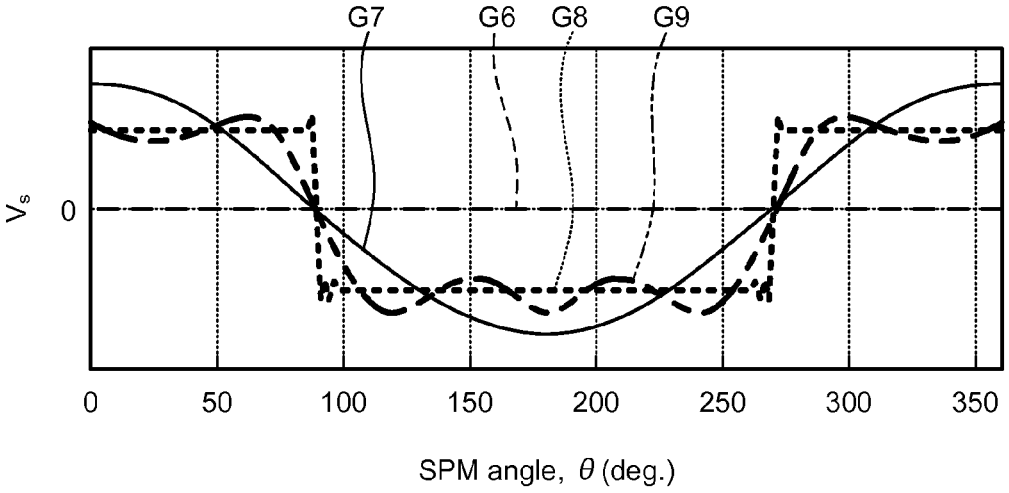

G7
G6
G8
G9
V_s
0
0
50
100
150
200
250
300
350
SPM angle, θ (deg.)

FIG.10

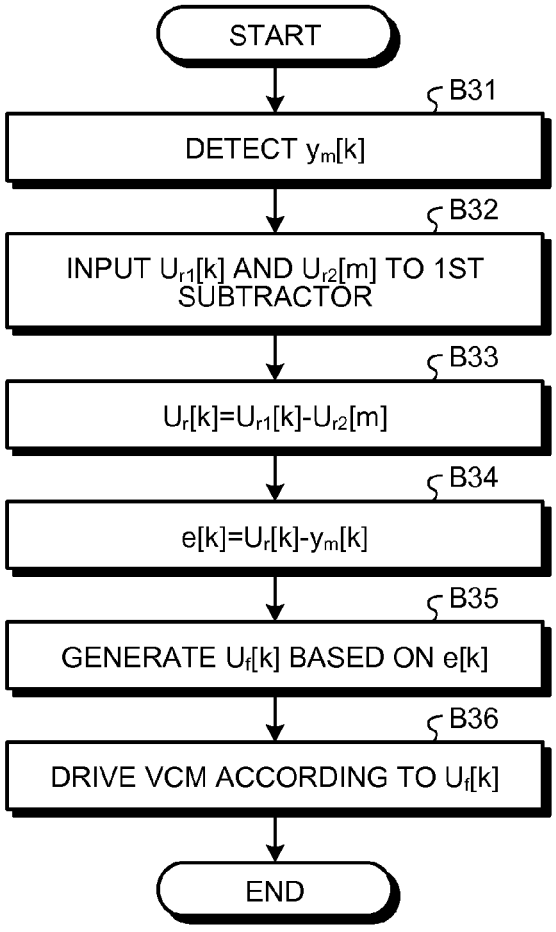
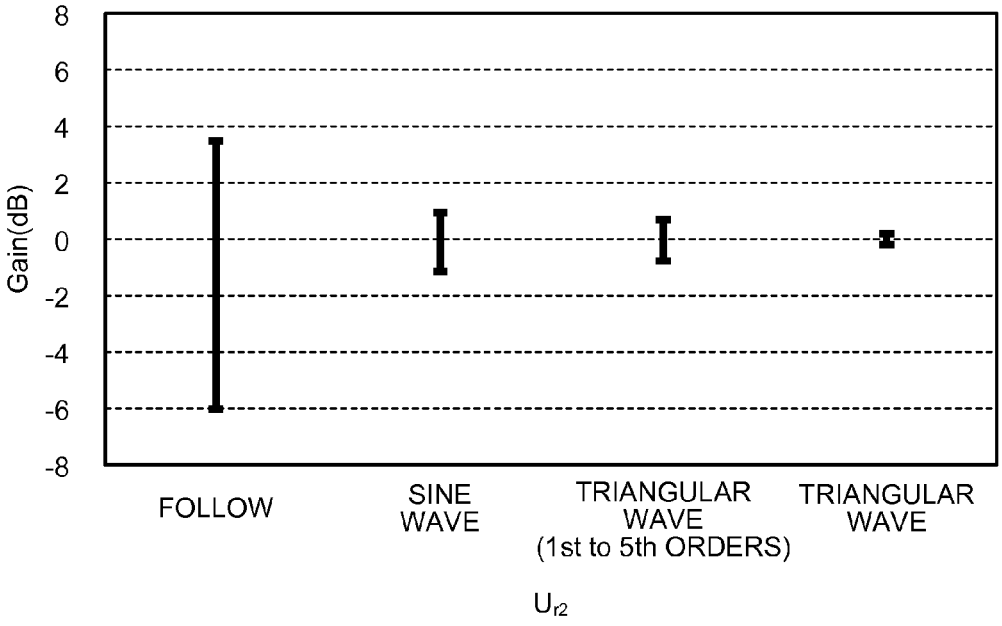

START
B31
DETECT $y_m[k]$
B32
INPUT $U_{r1}[k]$ AND $U_{r2}[m]$ TO 1ST SUBTRACTOR
B33
$U_r[k]=U_{r1}[k]-U_{r2}[m]$
B34
$e[k]=U_r[k]-y_m[k]$
B35
GENERATE $U_f[k]$ BASED ON e[k]
B36
DRIVE VCM ACCORDING TO $U_f[k]$
END

FIG.11


8
6
4
2
0
-2
-4
-6
-8
Gain(dB)
FOLLOW
SINE WAVE
TRIANGULAR WAVE (1st to 5th ORDERS)
TRIANGULAR WAVE
U_{r2}

SERVO WRITING METHOD, MAGNETIC DISK APPARATUS AND HEAD POSITION CONTROL METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from U.S. Provisional Application No. 62/171,440, filed on Jun. 5, 2015; the entire contents of which are incorporated herein by reference.

FIELD

Embodiments described herein relate generally to a servo writing method, a magnetic disk apparatus and a head position control method.

BACKGROUND

In magnetic disk apparatuses such as hard disks, servo patterns are written as servo information indicating information about positions on a magnetic disk. In the magnetic disk apparatus, by reading servo information from these servo patterns, a magnetic head can be moved to a target track.

The process of writing servo patterns onto the magnetic disk is called servo writing and is generally executed in the production process for magnetic disk apparatuses. In the conventional art, servo patterns are written at predetermined intervals (track pitches) to form tracks shaped like concentric circles or a spiral-shaped track with respect to the rotation center of the magnetic disk.

However, the track pitch of servo patterns may vary due to the influence of disturbance experienced during servo writing. If variation of the track pitch is large, servo gain varies, so that accuracy in detecting the head position, that is, accuracy in positioning the head decreases, and thus a malfunction such as a read error is likely to occur. Accordingly, a technique for reducing the influence of variation in the track pitch is desired.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing an example of the hardware configuration which a magnetic disk apparatus of an embodiment has;

FIG. **2** is a block diagram showing an example configuration of a servo-write control unit that the magnetic disk apparatus of the embodiment comprises;

FIG. **3** is a diagram showing examples of a second specifying value U_{r2} according to the embodiment;

FIG. **4** is a diagram for explaining servo tracks written on a magnetic disk of the embodiment;

FIG. **5** is a flow chart showing an example procedure of a servo write process according to the embodiment;

FIG. **6** is a flow chart showing an example procedure of a during-servo process according to the embodiment;

FIG. **7** is a block diagram showing an example configuration of a head position control unit that the magnetic disk apparatus of the embodiment comprises;

FIG. **8** is a diagram showing an example relation between servo tracks and data tracks according to the embodiment;

FIG. **9** is a diagram showing examples of traverse velocity V_S according to the embodiment;

FIG. **10** is a flow chart showing an example procedure of a head position control process according to the embodiment; and

FIG. **11** is a diagram for explaining an effect of suppressing variation of the embodiment.

DETAILED DESCRIPTION

In general, according to one embodiment, a servo writing method for a magnetic disk apparatus which comprises a magnetic disk and a head is provided. The servo writing method rotates the magnetic disk. The method derives a path obtained by adding a second specifying value to a first specifying value, the first specifying value corresponding to a separation distance from a rotation center of the magnetic disk, the second specifying value periodically displacing the separation distance in a radial direction synchronously with a rotation angle of the magnetic disk, the second specifying value being a value in which the separation distances at a start point and an end point of one rotation of the magnetic disk coincide. And, while causing the head to follow the path, the method writes servo information onto the magnetic disk with the head.

The servo writing method, magnetic disk apparatus, and head position control method according to an embodiment will be described in detail below with reference to the accompanying drawings. The present invention is not limited to this embodiment.

FIG. **1** is a block diagram showing an example of the hardware configuration which a magnetic disk apparatus **100** of the present embodiment has. A magnetic disk **111** is a disk-shaped recording medium, and one or a plurality of magnetic disks **111** are provided along an axial direction of the rotation axis. The magnetic disk **111** is rotated by a spindle motor (SPM) **112** with the rotation axis (rotation center RC) as the center at predetermined rotation speed. Note that the SPM **112** is driven by a motor driver **121**.

A magnetic head **122** is provided at tip portion of an actuator arm **115**. The magnetic head **122** is moved by a voice coil motor (VCM) **116** driven by the motor driver **121** in radial directions of the magnetic disk **111**. While the rotation of the magnetic disk **111** is stopped, the magnetic head **122** is evacuated onto a ramp **123**. Note that the number of magnetic heads **122** (actuator arms **115**) is not limited to any number, but that a corresponding number of magnetic heads to the number of magnetic disks **111** are provided.

The magnetic head **122** has a write head and a read head (not shown). The write head writes data onto the magnetic disk **111**. The read head reads data from the magnetic disk **111**.

A head amplifier **124** amplifies the signal read by the magnetic head **122** from the magnetic disk **111** to supply to a RDC (Read Write Channel) **125**. Further, the head amplifier **124** amplifies a signal supplied from the RDC **125** to write data onto the magnetic disk **111** and supplies to the magnetic head **122**.

The RDC **125** code modulates data to be written onto the magnetic disk **111** supplied from an HDC **131** described later to supply to the head amplifier **124**. Further, the RDC **125** code demodulates a signal supplied from the head amplifier **124** into digital data to output to the HDC **131**.

A CPU (Central Processing Unit) **126** is a processor of the magnetic disk apparatus **100**. An SRAM (Static Random Access Memory) **127** that is a for-operation memory, a flash ROM (Read Only Memory) **128** that is a nonvolatile memory, and a for-temporary-storage buffer RAM **129** are connected to the CPU **126**.

The flash ROM **128** stores various programs (firmware, etc.) related to the operation of the magnetic disk apparatus **100**. Further, the flash ROM **128** stores a variety of setting information related to the operation of the magnetic disk apparatus **100**. For example, the flash ROM **128** stores a table in which first specifying values U_{r1} are associated with second specifying values U_{r2} as setting information. Here, the first specifying value U_{r1} is data specifying the radial position of a track (a track number or cylinder number). The radial position is the distance measured in a radial direction from the rotation center RC of the magnetic disk **111** to the track. An equal number of first specifying values U_{r1} to the number of tracks or cylinders written on the magnetic disk **111** are prepared. A second specifying value U_{r2} is prepared for each first specifying value U_{r1}. An equal number of second specifying values U_{r2} to the number of tracks written on the magnetic disk **111** may be prepared, or a second specifying value U_{r2} may be prepared for each of the zones partitioned along the radius. Further, second specifying values U_{r2} may be prepared for each magnetic head **122** or cylinder, or may be common to, not depending on, the magnetic heads **122** or cylinders. The details of the second specifying value U_{r2} will be described later.

The HDC (Hard Disk Controller) **131** provides the CPU **126** with access to/from function units such as the RDC **125**. Further, the HDC **131** provides the CPU **126** with access to/from a host computer (host) **40**. For example, the HDC **131** performs control of transmission/reception of data to/from the host computer (host) **40** via an I/F bus and control of the buffer RAM **129**. The buffer RAM **129** is used as a cache for data which is to be transmitted to or has been received from the host **40**.

The CPU **126** controls the operation of the magnetic disk apparatus **100** comprehensively by cooperating with a program stored in the flash ROM **128**. For example, the magnetic disk apparatus **100** performs servo writing to write servo information onto the magnetic disk **111** under the control of the CPU **126**. The servo information includes a variety of information used to detect the position of the magnetic head **122** (hereinafter called a head position) in a radial direction over the magnetic disk **111**. The servo information includes, e.g., servo marks, cylinder numbers, track numbers, sector numbers, a burst signal, and so on.

Further, the magnetic disk apparatus **100** performs head-position control to position the magnetic head **122** in a target position based on servo information written on the magnetic disk **111** and traversing velocity V_S described later under the control of the CPU **126**.

In the conventional art, servo writing at a predetermined track interval (SvTP: Servo track pitch) is performed to form concentric circle-shaped tracks with respect to the rotation center RC of the magnetic disk **111**. However, the SvTP may vary due to the influence of disturbance experienced at the time of servo writing. As an example of this disturbance, low-frequency noise lower than the rotation frequency of the SPM **112** can be cited. If variation in the SvTP is large, servo gain varies (oscillates), so that accuracy in detecting the head position decreases, and thus a malfunction such as a read error is likely to occur.

Accordingly, the magnetic disk apparatus **100** of the present embodiment performs processing to reduce the influence of variation in the SvTP when performing servo writing and head-position control. Specifically, the magnetic disk apparatus **100** performs servo writing with following servo tracks formed by adding sinusoidal waves or triangular waves to concentric circle-shaped tracks with respect to the rotation center RC. Further, when performing writing or reading data or so on for the magnetic disk **111**, the magnetic disk apparatus **100** controls the head position to describe concentric circles with respect to the rotation center RC. The control system of the magnetic disk apparatus **100** will be described below.

First, a control system related to servo writing (a servo-write control unit **20**) that the magnetic disk apparatus **100** comprises will be described. FIG. **2** is a block diagram showing an example configuration of the servo-write control unit **20** that the magnetic disk apparatus **100** comprises.

As shown in FIG. **2**, the servo-write control unit **20** comprises a first adder **21**, a subtractor **22**, a controller **23**, a second adder **24**, and a positioning mechanism unit **25**. Note that part or all of the servo-write control unit **20** may be constituted by software, which is implemented by the CPU **126** and a program cooperating. Or part or all of the servo-write control unit **20** may be constituted by hardware, which is implemented by a dedicated processor. Or part or all of the servo-write control unit **20** may be implemented by other function units such as the motor driver **121** and the HDC **131**.

The CPU **126** sequentially reads the first specifying value U_{r1} and the second specifying value U_{r2} of each track from the table in the flash ROM **128** and inputs to the first adder **21**. The first specifying value U_{r1} specifies a fixed radial position on the magnetic disk **111**. The second specifying value U_{r2} specifies a varying value by which to displace the first specifying value U_{r1} continuously through one rotation along the circular track with the rotation center RC as the center and with the radial position specified by the first specifying value U_{r1} as the radius.

As an example of the second specifying value U_{r2}, a sinusoidal wave U_{r2_sin} expressed by the following equation (1) can be used. Here, A is an amplitude; θ is the rotation angle of the SPM **112**; and θ_{ofs} is an arbitrary offset from the rotation angle θ.

$$U_{r2_sin}=A\sin(\theta+\theta_{ofs}) \tag{1}$$

Or as another example of the second specifying value U_{r2}, a triangular wave U_{r2_tri} expressed by the following equation (2) can be used.

$$U_{r2_tri}=A\frac{8}{\pi^2}\sum_{k-1}^{\infty}\left\{\sin\left(\frac{k\pi}{2}\right)\frac{\sin(k(\theta+\theta_{ofs}))}{k^2}\right\} \tag{2}$$

Here, the second specifying value U_{r2} is adjusted so that the radial positions at the start point and the end point of the circular track specified by the first specifying value U_{r1} coincide. More specifically, the period or wavelength of the sinusoidal wave U_{r2_sin} or the triangular wave U_{r2_tri} is adjusted so that one rotation of the circular track specified by the first specifying value U_{r1} coincides with n periods thereof, where n is ½ or an integer of one or greater. The amplitude A is set at a value greater than the SvTP (e.g., 15 times the SvTP). Where the triangular wave U_{r2_tri} is used, the upper limit of the order k, that is, the number of sinusoidal components in the composite is not limited to any number. For example, the second specifying value U_{r2} may be a low-order component of the triangular wave U_{r2_tri} composed of the first order to the fifth order (k=1 to 5).

FIG. **3** is a diagram showing examples of the second specifying value U_{r2}. The horizontal axis represents the rotation angle θ of the SPM **112**. The vertical axis represents the value (amplitude δ) of the second specifying value U_{r2} with the first specifying value U_{r1} as a reference value (0).

The graph G1 denotes the case where the second specifying value U_{r2} is zero, that is, the circular track specified by the first specifying value U_{r1}. The graph G2 denotes the track in the case where the sinusoidal wave U_{r2_sin} is used as the second specifying value U_{r2}. The graph G3 denotes the track in the case where the triangular wave U_{r2_tri} is used as the second specifying value U_{r2}.

As shown in FIG. **3**, the second specifying value U_{r2} displaces the radial position specified by the first specifying value U_{r1} periodically (continuously) synchronously with the rotation angle θ. Where a low-order component of the triangular wave U_{r2_tri} is used as the second specifying value U_{r2}, the track is in a shape as denoted by the graph G4.

The track of the graph G4 is in a shape asymptotic to the graph G2 as compared with the graph G3. Although FIG. **3** shows an example where one rotation of the circular track specified by the first specifying value U_{r1} is one period of the second specifying value U_{r2}, the invention is not limited to this. For example, the period of the second specifying value U_{r2} may be set at ½ or an integer of one or greater as mentioned above.

In the present embodiment, the table in the flash ROM **128** holds one rotation worth of position correction information representing the above-described sinusoidal wave U_{r2_sin} or triangular wave U_{r2_tri} as the second specifying value U_{r2}. For example, if a cylinder (track) of the magnetic disk **111** has 400 sectors, the second specifying value U_{r2} holds 400 of position correction information corresponding to the sectors for that cylinder.

Referring back to FIG. **2**, the first adder **21** adds the second specifying value U_{r2} to the first specifying value U_{r1}. The first adder **21** outputs the result of adding the first specifying value U_{r1} and the second specifying value U_{r2} as a target position U_r to the subtractor **22**. The subtractor **22** calculates the offset of an observed head position y_m from the target position U_r as a deviation e ($=U_r-y_m$).

The controller **23** generates a manipulation amount U_{f_FE} based on the deviation e. The second adder **24** adds an FF control amount U_{f_FF} to the manipulation amount U_{r_FB}. The second adder **24** outputs the result of adding the manipulation amount U_{f_FB} and the FF control amount U_{f_FF} as a manipulation amount U_f to the positioning mechanism unit **25**.

Here, the FF control amount U_{f_FF} is a feedback control amount (manipulation amount) for suppressing the influence of disturbance d_1 applied at the time of servo writing. The FF control amount U_{f_FF} can be obtained through learning repetitive control or the like. In the present embodiment, for example, the CPU **126** determines the FF control amount U_{f_FF} to be inputted to the second adder **24** based on the detecting result of a sensor (not shown) that detects a signal correlated with disturbance d_1. Then the second adder **24** adds the FF control amount U_{f_FF} to the manipulation amount U_{f_FB} to output the manipulation amount U_f with which accuracy in following the second specifying value U_{r2} is heightened.

The positioning mechanism unit **25** drives the VCM **116** according to the manipulation amount U_f given from the second adder **24**. That is, the positioning mechanism unit **25** moves the actuator arm **115** in a radial direction of the magnetic disk **111**. Thus, the magnetic head **122** is positioned in an actual head position y.

The servo-write control unit **20** detects the head position of the magnetic head **122** based on servo information and the like written on the magnetic disk **111** under the control of the CPU **126**. Here, the head position actually detected is the observed head position y_m that is disturbance d_1 at servo writing added to the actual head position y. The method of detecting the observed head position y_m at servo writing is a publicly known technique, and hence description thereof is omitted.

Then the servo-write control unit **20**, with the FF control amount U_{f_FF} and the observed head position y_m being inputted thereto, repeats the operation of writing new servo tracks at predetermined track pitches (SvTPs). Thus, multiple tracks worth of servo information is written as servo tracks onto the magnetic disk **111**. The magnetic disk apparatus **100** may be configured such that the CPU **126** inputs the FF control amount U_{f_FF} and the observed head position y_m or that another function unit (e.g., the HDC **131**) inputs them.

FIG. **4** is a diagram for explaining servo tracks written on the magnetic disk **111**. The plane formed by an X axis and a Y axis corresponds to a disk surface of the magnetic disk **111**. Further, the point P1 in the middle of this plane corresponds to the rotation center RC of the SPM **112** (the magnetic disk **111**). Yet further, angles 0, 90, 180, and 270 plotted on the X axis and Y axis correspond to the rotation angle θ of the SPM **112**. Note that FIG. **4** shows a servo track written for a certain first specifying value U_{r1}.

The servo track ST1 denotes a servo pattern in the case where the second specifying value U_{r2} is zero, that is, where only the first specifying value U_{r1} is used. As shown in FIG. **4**, the path formed by the servo track ST1 is in a circular shape (concentric circle) with the point P1 as the center. The servo track ST2 denotes a path in the case where the second specifying value U_{r2} is the sinusoidal wave U_{r2_sin}. The servo track ST3 denotes a path in the case where the second specifying value U_{r2} is the triangular wave U_{r2_tri}. Note that FIG. **4** shows examples where one period of the second specifying value U_{r2} is one rotation of the circular path specified by the first specifying value U_{r1}.

As shown in FIG. **4**, the paths formed by the servo tracks ST2, ST3 are shaped in closed curves obtained by displacing each radial position on the servo track ST1 by the amplitude δ according to the rotation angle θ. For example, the path formed by the servo track ST2 is in a circular shape with the point P2 offset by the amplitude δ from the point P1 at an angle of 90 degrees, where the amplitude δ is maximal (δ=A), as the center. The path formed by the servo track ST3 is generally in a heart shape with the point P2 as the center as in the servo track ST2 and with its tip being at the position of an angle of 90 degrees, where the amplitude δ is maximal (δ=A).

As such, the servo-write control unit **20** performs servo writing based on the target position U_r obtained by adding the second specifying value U_{r2} specifying the sinusoidal wave U_{r2_sin} or triangular wave U_{r2_tri} to the first specifying value U_{r1} specifying one of concentric circle-shaped tracks. Thus, servo tracks written on the magnetic disk **111** form non-concentric circle-shaped paths, whose distances (radial positions) from the rotation center RC vary continuously through one rotation.

Next, the operation at the time of servo writing will be described with reference to FIGS. **5** and **6**. The servo writing can be divided into a servo write process of writing servo information onto each cylinder (track) and a during-servo process that is performed while writing servo information. First, the servo write process will be described with reference to FIG. **5**.

FIG. **5** is a flow chart showing an example procedure of the servo write process. Although this process describes an

example where NULL-type servo information (servo pattern) is written, the type of the servo pattern is not limited to this.

For the NULL-type servo pattern, a burst pattern formed of an N phase and a Q phase is used. As the N phase and Q phase, magnetization patterns can be placed in which the polarity is inverted alternately at intervals of 180 degrees (=1 cylinder) when going along a radial direction of the magnetic disk **111**. Further, the N phase and Q phase can be offset in phase from each other by 90 degrees (=0.5 cylinder) when going along a radial direction of the magnetic disk **111**. For example, the N phase can be placed such that the polarity is inverted at the boundaries between adjacent tracks, and the Q phase can be placed such that the polarity is inverted at the center of each track.

The CPU **126** sets the cylinder number n to an initial value of 1, thereby setting the cylinder that is a first write position (B**11**). Then the CPU **126** positions the head position over the cylinder corresponding to the cylinder number n (B**12**).

Then the CPU **126** cooperates with the RDC **125** and the like to write a servo pattern (servo track) onto the magnetic disk **111** (B**13**). Note that while writing a servo track, the servo-write control unit **20** performs the during-servo process (see FIG. **6**).

When finishing writing the servo pattern for the cylinder number n, the CPU **126** determines whether the cylinder number n has reached an end number (B**14**). If determining that the cylinder number n has not reached the end number (No at B**14**), the CPU **126** sets 0.5 (cylinder) added to the cylinder number n as a new cylinder number n (B**15**) and returns to B**12**. Note that the CPU **126** writes servo patterns whose phases are offset from each other by 90 degrees for a cylinder number whose first digit after decimal point is zero and a cylinder number whose first digit after decimal point is 5.

On the other hand, if determining that the cylinder number n has reached the end number at B**14** (Yes at B**14**), the CPU **126** finishes this process.

Next, the during-servo process will be described with reference to FIG. **6**. FIG. **6** is a flow chart showing an example procedure of the during-servo process. This process is executed while writing a servo pattern in the above-described servo write process.

First, the CPU **126** detects the observed head position $y_m[k]$ of the magnetic head **122** (B**21**). Then the CPU **126** inputs the first specifying value $U_{r1}[k]$ and the second specifying value $U_{r2}[m]$ to the first adder **21** (B**22**). Here, the first specifying value $U_{r1}[k]$ is the first specifying value U_{r1} for sample number k that specifies the cylinder (track) detected at the observed head position $y_m[k]$. The second specifying value $U_{r2}[m]$ is data for the sector (of sector number m) to perform servo writing on from among second specifying values U_{r2} registered in association with the first specifying value $U_{r1}[k]$. For example, if the cylinder has 400 sectors, 400 second specifying values U_{r2} are sequentially inputted.

The first adder **21** adds the first specifying value $U_{r1}[k]$ and the second specifying value $U_{r2}[m]$ to calculate the target position $U_r[k]$ (B**23**). Then the subtractor **22** takes the difference between the target position $U_r[k]$ and the observed head position $y_m[k]$ to calculate the deviation e[k] (B**24**). Then the controller **23** and the second adder **24** generates the manipulation amount $U_f[k]$ based on the deviation e[k] (B**25**).

Then the positioning mechanism unit **25** drives the VCM **116** according to the manipulation amount $U_f[k]$, thereby moving the magnetic head **122** to the target position $U_r[k]$ (B**26**). The observed head position $y_m[k]$ of the magnetic head **122** moved by driving the VCM **116** is inputted recursively to the subtractor **22**.

Next, a control system related to head-position control (a head position control unit **30**) that the magnetic disk apparatus **100** comprises will be described. FIG. **7** is a block diagram showing an example configuration of the head position control unit **30** that the magnetic disk apparatus **100** comprises.

As shown in FIG. **7**, the head position control unit **30** comprises a first subtractor **31**, a second subtractor **32**, a controller **33**, and a positioning mechanism unit **34**. Note that part or all of the head position control unit **30** may be constituted by software, which is implemented by the CPU **126** and a program cooperating. Or part or all of the head position control unit **30** may be constituted by hardware, which is implemented by a dedicated processor. Or part or all of the head position control unit **30** may be implemented by other function units such as the motor driver **121** and the HDC **131**.

The CPU **126** inputs the first specifying value U_{r1} for a track or sector on which to perform writing or reading data or so on and the second specifying value U_{r2} corresponding to that the first specifying value U_{r1} to the first subtractor **31**. The first subtractor **31** subtracts the second specifying value U_{r2} from the first specifying value U_{r1} to output the subtracting result as the target position U_r to the second subtractor **32**. The second subtractor **32** calculates the difference between the target position U_r and the observed head position y_m as the deviation e ($=U_r-y_m$).

The controller **33** generates the manipulation amount U_f to be given to the positioning mechanism unit **34** based on the deviation e. The positioning mechanism unit **34** drives the VCM **116** according to the manipulation amount U_f given from the controller **33**. Thus, the magnetic head **122** is positioned in the actual head position y.

The head position control unit **30** detects the head position of the magnetic head **122** based on servo information read by the magnetic head **122**, the traversing velocity V_S described later, and the like under the control of the CPU **126**. Here, the head position actually detected is the observed head position y_m that is a path L, RRO (Repeatable RunOut), and disturbance d_2 added to the actual head position y. The path L is the path formed by the servo track written on the magnetic disk **111** according to the second specifying value U_{r2} in the servo write process. The RRO is a component corresponding to disturbance d_1 in the servo writing. The disturbance d_2 is a disturbance component applied when controlling the head position.

The head position control unit **30** recursively performs operation of positioning the magnetic head **122** in the target position U_r while detecting the observed head position y_m. The magnetic disk apparatus **100** may be configured such that the CPU **126** detects (inputs) the observed head position y_m or that another function unit (e.g., the HDC **131**) detects (inputs) it. The method of detecting the observed head position y_m is a publicly known technique, and hence description thereof is omitted.

In the above-described configuration of the head position control unit **30**, the second subtractor **32** subtracts the observed head position y_m from the target position U_r. By this subtraction, the component of the second specifying value U_{r2} in the target position U_r cancels out the component of the path L (the second specifying value U_{r2}) written in the servo write process. Therefore, the deviation e calculated by the second subtractor **32** is one obtained by removing the component of the second specifying value U_{r2} from the

target position U_r. Thus, the actual head position y of the magnetic head **122** does not follow servo tracks but forms concentric circle-shaped paths with respect to the rotation center RC. Hence, the magnetic head **122** is substantially fixed over the track corresponding to the first specifying value U_{r1} (the target position U_r), so that as the magnetic disk **111** rotates, the magnetic head **122** goes across servo tracks written on the magnetic disk **111**.

For example, when the radial position P**3** on the magnetic disk **111** shown in FIG. **4** is specified by the first specifying value U_{r1} (the target position U_r), the head position control unit **30** positions the magnetic head **122** in this radial position P**3**. In this case, the path of the magnetic head **122** is circular (in a concentric-circle shape) with respect to the point P**1** since the magnetic disk **111** rotates around the point P**1** (the rotation center RC). Further, the magnetic head **122** is substantially fixed over the magnetic disk **111**, so that as the magnetic disk **111** rotates, the magnetic head **122** goes across the servo track ST**2** (or ST**3**). For example, in the situation shown in FIG. **4**, the magnetic head **122** is located outside the servo track ST**2**, but when the magnetic disk **111** rotates through 90 degrees, the magnetic head **122** crosses the servo track ST**2** to be located inside.

FIG. **8** is a diagram showing an example relation between servo tracks and data tracks. In FIG. **8**, the horizontal axis represents the rotation angle θ of the SPM **112**. The vertical axis represents the track number for servo tracks written on the magnetic disk **111**. Note that in FIG. **8** the paths of servo tracks are indicated by straight lines.

A graph G**5** on the right of FIG. **8** represents the state of the SvTP between servo tracks. In the graph G**5**, deviation to the left means that the SvTP becomes larger. Also with the servo writing method of the present embodiment, since being affected by the aforementioned disturbance d_1, the SvTP varies between servo tracks as shown by the graph G**5**.

For example, in the case where servo tracks are based on the sinusoidal wave U_{r2_sin}, the head position control unit **30** controls the head position to follow the path of a data track DT**2** to remove the component of this sinusoidal wave U_{r2_sin}. In the case where servo tracks are based on the triangular wave U_{r2_tri}, the head position control unit **30** controls the head position to follow the path of a data track DT**3** to remove the component of this triangular wave U_{r2_tri}. By this means, the paths of the data tracks DT**2**, DT**3** are circular (in a concentric-circle shape) with respect to the rotation center RC. The data track DT**1** is the path in the case of following the servo track.

As shown in FIG. **8**, the velocity V of the magnetic head **122** relative to a servo track can be decomposed into two components, velocity V_θ in a circumferential direction and velocity (traverse velocity) V_S in a radial direction. That is, the magnetic head **122** crosses servo tracks at traverse velocity V. Although FIG. **8** illustrates the velocity V for the data track DT**3**, the same applies to the data track DT**2**.

The head position control unit **30** detects the observed head position y_m from servo information obtained by the magnetic head **122** crossing servo tracks, the traverse velocity V_S, and the like and recursively performs operation of positioning the magnetic head **122** in the target position U_r based on the observed head position y_m. That is, the head position control unit **30** detects and adjusts the observed head position y_m using multiple servo tracks which the magnetic head **122** has crossed.

As such, the magnetic disk apparatus **100** of the present embodiment detects and adjusts the head position using multiple servo tracks, thereby being able to reduce the influence of variation in the SvTP occurring between the servo tracks by an averaging effect. Thus, the magnetic disk apparatus **100** of the present embodiment can suppress variation in servo gain and improve accuracy in detecting the head position.

It is understood that as the traverse velocity V_S becomes larger, an offset is more likely to occur in the observed head position y_m detected. Hence, in order to reduce an offset of the demodulated position, it is preferable to decrease the maximum of the traverse velocity V_S.

FIG. **9** is a diagram showing examples of the traverse velocity V_S. The horizontal axis represents the rotation angle θ of the SPM **112**. The vertical axis represents the traverse velocity V_S. The graph G**6** indicates the traverse velocity V_S in the case where the second specifying value U_{r2} is zero, that is, the head follows a servo track. The graph G**7** indicates an example of the traverse velocity V_S in the case where the sinusoidal wave U_{r2_sin} is used as the second specifying value U_{r2}. The graph G**8** indicates an example of the traverse velocity V_S in the case where the triangular wave U_{r2_tri} is used as the second specifying value U_{r2}. Note that the graphs G**6** to G**8** of FIG. **9** correspond to the graphs G**1** to G**3** illustrated in FIG. **3** respectively.

As shown in FIG. **9**, the graphs G**7**, G**8** have shapes corresponding to the waveforms of the sinusoidal wave U_{r2_sin} and the triangular wave U_{r2_tri} respectively. The graph G**8** based on the triangular wave U_{r2_tri} is seen to be lower in the maximum of the traverse velocity V_S when comparing the graphs G**7**, G**8**. Hence, by using the triangular wave U_{r2_tri} to write a servo track, an offset of the demodulated position can be reduced as compared with writing a servo track based on the sinusoidal wave U_{r2_sin}.

The graph G**9** indicates an example of the traverse velocity V_S in the case where a low-order component of the triangular wave U_{r2_tri} is used as the second specifying value U_{r2}. Note that the graph G**9** corresponds to the graph G**4** illustrated in FIG. **3**.

As shown in FIG. **9**, the graph G**9** varies more smoothly than the graph G**8** and is closer in shape to the graph G**7**. It is understood that the maximum of the traverse velocity V_S of the graph G**9** is lower than the maximum of the graph G**7**. Therefore, by using a low-order component of the triangular wave U_{r2_tri} to write a servo track, the effect of reducing an offset of the demodulated position is reduced as compared with the case of using the triangular wave U_{r2_tri}, but is improved as compared with the case of using the sinusoidal wave U_{r2_sin}.

FIG. **10** is a flow chart showing an example procedure of the head position control process executed by the head position control unit **30** shown in FIG. **7**. This process is executed to perform reading or writing data or so on for a specific track or sector.

First, the CPU **126** detects the observed head position $y_m[k]$ of the magnetic head **122** (B**31**). Then the CPU **126** inputs the first specifying value $U_{r1}[k]$ and the second specifying value $U_{r2}[m]$ to the first subtractor **31** based on the observed head position $y_m[k]$ (B**32**). Here, the first specifying value $U_{r1}[k]$ is the first specifying value U_{r1} for sample number k that specifies the cylinder (track) detected at the observed head position $y_m[k]$. The second specifying value $U_{r2}[m]$ is data for the sector (of sector number m) to perform servo writing on from among second specifying values U_{r2} registered in association with the first specifying value $U_{r1}[k]$. For example, if the cylinder has 400 sectors, 400 second specifying values U_{r2} are sequentially inputted.

Then the first subtractor **31** subtracts the second specifying value $U_{r2}[m]$ from the first specifying value $U_{r1}[k]$ to calculate the target position $U_r[k]$ (B**33**). Then the second

subtractor **32** takes the difference between the target position $U_r[k]$ and the observed head position $y_m[k]$ to calculate the deviation e[k] (B**34**). Then the controller **33** generates the manipulation amount $U_f[k]$ based on the deviation e[k] (B**35**).

Then the positioning mechanism unit **34** drives the VCM **116** according to the manipulation amount $U_f[k]$, thereby moving the magnetic head **122** to the target position $U_r[k]$ (B**36**). The observed head position $y_m[k]$ of the magnetic head **122** moved by driving the VCM **116** is inputted recursively to the second subtractor **32**.

FIG. **11** is a diagram for explaining the effect of suppressing variation by the servo writing method and head position control method of the present embodiment. In FIG. **11**, the horizontal axis represents the type of the second specifying value U_{r2} that the first subtractor **31** subtracts from the first specifying value U_{r1}. Here, "FOLLOW" corresponds to the case of causing the head position to follow a servo track servo-written based on the sinusoidal wave U_{r2_sin}. "SINE WAVE" corresponds to the case where the sinusoidal wave U_{r2_sin} is used as the second specifying value U_{r2}. "TRIANGULAR WAVE (1st to 5th ORDERS)" corresponds to the case where a low-order component of the triangular wave U_{r2_tri} is used as the second specifying value U_{r2}. "TRIANGULAR WAVE" corresponds to the case where the triangular wave U_{r2_tri} is used as the second specifying value U_{r2}.

The vertical axis of FIG. **11** represents the servo gain. The servo gains for the types were obtained through simulation under the following conditions.

Interval between servo tracks (SvTP): 63.5 nm

Variation in SvTP: a sinusoidal wave of from 0.5 to 1.5 times

Period of variation in SvTP: 10 SvTPs

Number of sectors included in a servo track: 400

First specifying value U_{r1}: 20 mm

Amplitude A of the second specifying value U_{r2}: 1 μm

As shown in FIG. **11**, the range of variation in the servo gain when causing the head to follow a servo track is larger than in the case of using the sinusoidal wave U_{r2_sin} or the triangular wave U_{r2_tri}. As such, when the servo writing method and head position control method of the present embodiment are used, variation in the servo gain associated with variation in SvTP can be suppressed. Further, because the maximum of the traverse velocity V_S is lower when using the triangular wave U_{r2_tri} than when using the sinusoidal wave U_{r2_sin}, variation in the servo gain associated with variation in SvTP can be more efficiently suppressed.

While an embodiment has been described, this embodiment has been presented by way of example only, and is not intended to limit the scope of the inventions. Indeed, the novel embodiment described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiment described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

For example, in the above embodiment, the self-servo writing configuration where the magnetic disk apparatus **100** itself performs servo writing has been described, but the invention is not limited to this. Specifically, the magnetic disk apparatus **100** may be configured such that a magnetic disk **111** onto which servo tracks have been written by an external apparatus different from the magnetic disk apparatus **100** is incorporated therein. Where this configuration is adopted, the external apparatus may comprise the servo-write control unit **20** to perform servo writing according to the above servo writing method.

Although in the above embodiment the magnetic disk apparatus is configured such that the first specifying value U_{r1} and the second specifying value U_{r2} are stored in a table before servo writing, the invention is not limited to this. For example, it may be configured such that, while determining the first specifying value U_{r1} and the second specifying value U_{r2}, it performs servo writing and stores the first specifying value U_{r1} and the second specifying value U_{r2} into a table.

Further, although in the above embodiment the magnetic disk apparatus is configured such that the second specifying value U_{r2} corresponding to the first specifying value U_{r1} is stored in a table, the invention is not limited to this. For example, it may be configured such that parameters (e.g., amplitude, phase, etc.) involved in creating the second specifying value U_{r2} are stored in association with the first specifying value U_{r1} in the flash ROM **128**. In this case, the CPU **126** generates the second specifying value U_{r2} using parameters in association with the first specifying value U_{r1} and performs servo writing and head-position control based on the first specifying value U_{r1} and the second specifying value U_{r2}. Where this configuration is adopted, the amount of information to be stored can be reduced as compared with the configuration where the second specifying value U_{r2} is stored as it is.

Yet further, although in the above embodiment the magnetic disk apparatus is configured such that the first specifying value U_{r1} and the second specifying value U_{r2} are stored in the flash ROM **128**, not being limited to this, it may be configured such that they are stored in another storage medium.

What is claimed is:

1. A servo writing method for a magnetic disk apparatus that comprises a magnetic disk and a head, the method comprising:

rotating the magnetic disk;

deriving a path shaped in a closed curve, the path shaped in the closed curve being a path that is offset from a concentric circle, the concentric circle having a rotation center of the magnetic disk as a center, the path shaped in the closed curve being obtained by adding a second specifying value to a first specifying value, the first specifying value corresponding to a separation distance from the rotation center of the magnetic disk, the second specifying value periodically displacing the separation distance in a radial direction synchronously with a rotation angle of the magnetic disk, the second specifying value being a value in which the separation distances at a start point and an end point of one rotation of the magnetic disk coincide; and,

while causing the head to follow the path shaped in the closed curve, writing servo information onto the magnetic disk with the head.

2. The method according to claim **1**, wherein the second specifying value specifies a sinusoidal wave.

3. The method according to claim **1**, wherein the second specifying value specifies a triangular wave.

4. The method according to claim **1**, wherein the second specifying value specifies a low-order component of a triangular wave.

5. The method according to claim **1**, further comprising:

sequentially inputting the respective first specifying values of a plurality of tracks of which the separation distances are different; and,

while causing the head to follow the path shaped in the closed curve of each track, writing the servo information that corresponds to each track onto the magnetic disk.

6. A magnetic disk apparatus comprising:

a magnetic disk that rotates, the magnetic disk being a disk onto which servo information is written, the servo information being written onto a path shaped in a closed curve, the path shaped in the closed curve being a path that is offset from a concentric circle, the concentric circle having a rotation center of the magnetic disk as a center, the path shaped in the closed curve being obtained by adding a second specifying value to a first specifying value, the first specifying value corresponding to a separation distance from the rotation center of the magnetic disk, the second specifying value periodically displacing the separation distance in a radial direction synchronously with a rotation angle of the magnetic disk, the second specifying value being a value in which the separation distances at a start point and an end point of one rotation of the magnetic disk coincide;

a head; and

a controller that:

calculates a target position obtained by subtracting the second specifying value from the first specifying value, the first specifying value specifying a radial position of a specific track over the magnetic disk, the second specifying value displacing a concentric circle-shaped path to the path shaped in the closed curve, the concentric circle-shaped path having the separation distance as a radius, the separation distance being a distance between the first specifying value and the rotation center,

detects, based on the servo information read from the magnetic disk with the head, the radial position of the head over the magnetic disk, and

positions the head to the calculated target position.

7. The apparatus according to claim **6**, wherein the second specifying value specifies a sinusoidal wave.

8. The apparatus according to claim **6**, wherein the second specifying value specifies a triangular wave.

9. The apparatus according to claim **6**, wherein the second specifying value specifies a low-order component of a triangular wave.

10. The apparatus according to claim **6**,

a storing unit that stores the first specifying value and the second specifying value that are associated with each other, or that stores the first specifying value and a parameter involved in creating the second specifying value that are associated with each other,

wherein the controller calculates the target position based on the first specifying value and the second specifying value, or based on the first specifying value and a parameter in association with the first specifying value stored in the storing unit.

11. A head position control method for a magnetic disk apparatus that comprises a magnetic disk that rotates and a head, the magnetic disk being a disk onto which servo information is written, the method comprising:

writing the servo information onto a path shaped in a closed curve, the path shaped in the closed curve being a path that is offset from a concentric circle, the concentric circle having a rotation center of the magnetic disk as a center, the path shaped in the closed curve being obtained by adding a second specifying value to a first specifying value, the first specifying value corresponding to a separation distance from the rotation center of the magnetic disk, the second specifying value periodically displacing the separation distance in a radial direction synchronously with a rotation angle of the magnetic disk, the second specifying value being a value in which the separation distances at a start point and an end point of one rotation of the magnetic disk coincide;

calculating a target position obtained by subtracting the second specifying value from the first specifying value, the first specifying value specifying a radial position of a specific track over the magnetic disk, the second specifying value displacing a circular concentric circle-shaped path to the path shaped in the closed curve, the circular concentric circle-shaped path having the separation distance as a radius, the separation distance being a distance between the first specifying value and the rotation center;

detecting, based on the servo information read from the magnetic disk with the head, the radial position of the head over the magnetic disk; and

positioning the head based on the radial position of the head.

12. The method according to claim **11**, wherein the second specifying value specifies a sinusoidal wave.

13. The method according to claim **11**, wherein the second specifying value specifies a triangular wave.

14. The method according to claim **11**, wherein the second specifying value specifies a low-order component of a triangular wave.

15. The method according to claim **11**, further comprising:

storing the first specifying value and the second specifying value that are associated with each other, or storing the first specifying value and a parameter involved in creating the second specifying value that are associated with each other; and

calculating the target position based on the stored first specifying value and the second specifying value, or based on the stored first specifying value and a parameter in association with the first specifying value.

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